Microprocessor Power

and Temperature Mapping

Power mapping is a method for determining the hot spots on a chipset's die surface. These are the areas where power density is at its highest. In electronics package design, it is prudent to maximize heat conduction away from areas of increased power level; after all, the location of a thermal failure will be in the hottest spot. By knowing where the areas of highest power generation are located on a chip, a package designer can focus on heat transfer capability from those sections. While this can also lead to increased reliability from a thermal consideration, cooling the hot spots can predictably lead to cost reduction on the board. If hot spots are unattended, increased cooling capability is required for the chipset, and the result will be a need for exotic or active heat sinks, often of high cost.

A power map refers to the two dimensional area where all of the transistors are stacked on the die. The map itself can be a color-coded or 3-dimensional surface plot where the heat flux is mapped. It is often not the magnitude of heat flux that is important, but the relative heat flux as compared to other parts on the chip.

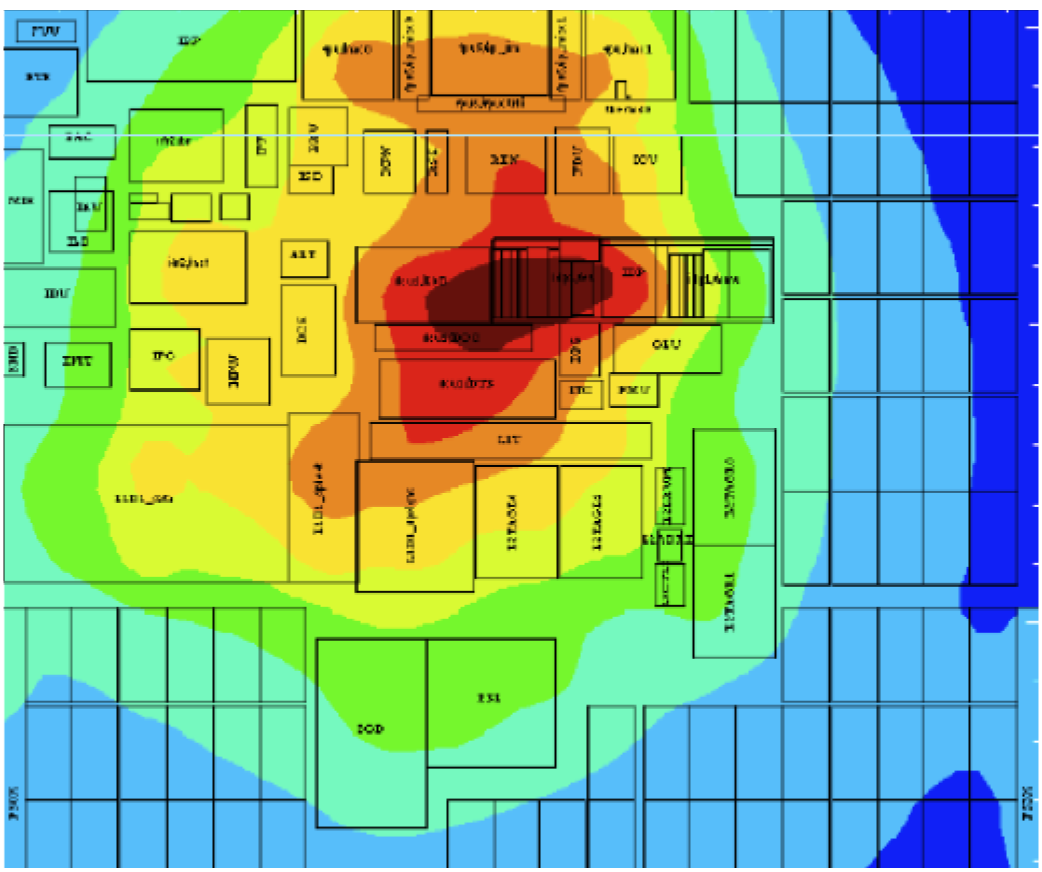

Figure 1. Color Contour Map Depicting Thermal Gradients on a Microprocessor [1].

The power mapping technique works as follows: the lids and caps which protect the die are removed and the chip is placed in a protective chamber. Then, the electrical activity of the chip is simulated for situations ranging from idle to full power consumption. At this point, a 2-dimensional temperature map can be obtained to determine the hot spots for different power consumptions. There are two main approaches for obtaining the temperature map: use of an infrared detector (IR) camera for infrared thermography, or use of a high resolution camera for liquid crystal thermography. For both approaches, some preparation of the chip is required prior to measurement. Liquid crystal thermography, in particular, involves coating the chip with layers of black paint and a liquid crystal solution, however, the result can yield more colorful photographs with higher contrast than some infrared cameras can provide.

Because a chip is exposed and stressed during the collection of a power map, heat removal can be a particular concern. For low power electronics, it may be suitable to do testing in the open air; but, for high power electronics, the chip must be immersed within a dielectric fluid. Alternatively, some form of transparent heat sink (which allows light to pass through) can be used to remove heat and prevent thermal failure. One particular design proposal uses a setup wherein a microprocessor is mounted within a duct that is filled with dielectric fluid and capped with a sapphire window [2]. A steady flow of fluid is pumped across the duct. The result is a clear view of the die surface while the chip is active. Because the device is immersed within a clear dielectric fluid, there is little chance of creating a short, and the constant flow helps prevent thermal failure.

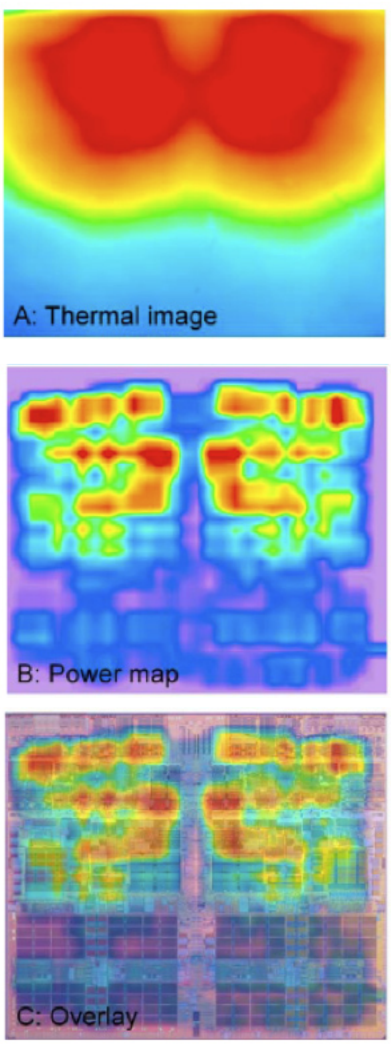

Figure 2. Overlaying a Thermal Image on a Photograph of Transistors to Highlight Hotspots. [2]

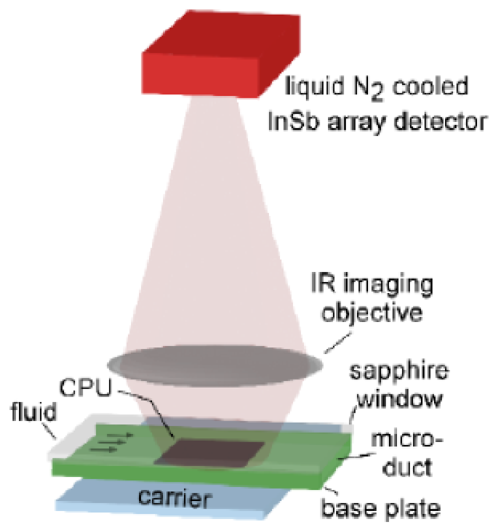

Figure 3. Proposed Setup for Obtaining a Power Map of a Microprocessor [2].

Once the power map is obtained, a designer can determine where the hot spots reside on the chip. If the problem is severe enough, a simple solution can be to add more metal near the hot spots to spread heat to cooler areas. One exotic and interesting method for cooling hot spots is through the use of microcoolers directly on the die itself, rather than bonded to it. These microcoolers are based on very small thermoelectric coolers doped directly onto the substrate [3]

In conclusion, while electronics are getting exponentially more sophisticated and the needs for thermal management escalate, minimizing the hot spots on a microprocessor becomes increasingly important. The use of a power map is important for detecting those hot spots. The point of failure on a microprocessor is likely to be the hottest point. Evening the temperature across the die is an effective way to reduce thermal failure and save costs by using less expensive heat sinks and requiring less airflow at the board level.

References:

1.Rusu, S., Trends and Challenges in High Performance Microprocessor Design, Intel Corp., 2004.
2.Mgrdichian, L., On-Chip Silicon 'Microcoolers' for Microprocessor Hot Spots, www.physorg.com, 2004.
3.Hamann, H., Lacey, J., Wegner, A. and Wakil, J., Spatially-Resolved Imaging of Microprocessor Power (SIMP): Hotspots in Microprocessors, ITHERM, 2006..